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Excessive Water Production Diagnostic and Control - Case Study Jake Oil Field - Sudan

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Abstract

For mature fields, Excessive water production is a complex subject in the oil and gas industries and has a serious economic and environmental impact. Some argue that oil industry is effectively water industry producing oil as a secondary output. Therefore, it is important to realize the different mechanisms that causing water production to better evaluate existing situation and design the optimum solution for the problem. This paper presents the water production and management situation in Jake oilfield in the southeast of Sudan; a cumulative of 14 MMBbl of water was produced till the end of 2014, without actual plan for water management in the field, only conventional shut-off methods have been tested with no success. Based on field production data and the previously applied techniques, this work identified the sources of water problems and attempts to initialize a strategy for controlling the excessive water production in the field. The production data were analyzed and a series of diagnostic plots were presented and compared with Chan's standard diagnostic plot. As a result, distinction between channeling and conning for each well was identified; the work shows that channeling is the main reason for water production in wells with high permeability sandstone zone while conning appears only in two wells. Finally, the wells were classified according to a risk factor and selections of the candidate wells for water shut off were presented.

Keywords: Water Management; Production Optimization; water shut off.

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1. Introduction

Since 1850, oil production was introduced as the major industrial activities in the word; it is considered as the important source of energy for many countries till today. During oil production, many problems (environmental effects, reduction of the net oil production and increases corrosion rates) were presented as a result of unwanted water production through oilfields; due to the large amount of water produced during oil production, some argue that oil industry is effectively water industry producing oil as a secondary output. In USA, the water production was approximately 21 billion barrels of water annually [3], when compared to the annual oil 1.9 billion barrels and 23.9 TCF gas, [4]. Channeling and coning are the major problems lead to excessive water production worldwide; other problems have limited prevalence.

The solution for the massive water production problems can be categorized into groups: Water Control Techniques and Water Disposal Techniques; it is well known that produced water has serious pollutants and causes thousands of deaths per day, mostly due to contamination of drinking water by untreated sewage in developing countries; therefore, the disposal techniques have to apply the standard regulations for environment before the water been spilt in the ground, which consequently increases the disposal costs from 30 to 40 US$ billion worldwide [5] and affect the economic feasibility of the field.

Operators have to differentiate between different types of water entering the well bottom hole; the problems can vary from simple such as tubing or casing leaks and oil water contact moving, to adequate problems such as high permeability layers or conning. Figure 1 is illustration of the main water production problems classified according to its complexity, the scale from 1 to 10.

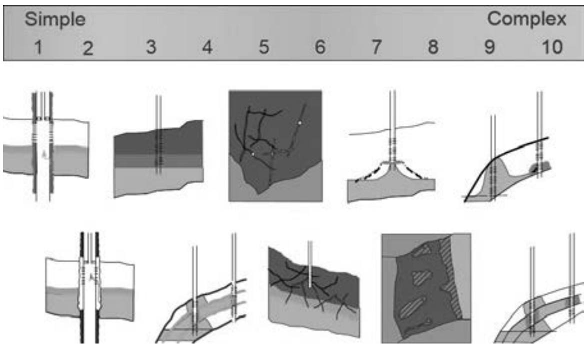


Figure 1: Produced Water Problems Scale. After [6]

When it desired to use a controlling techniques (mechanical or chemical shut-off), an adequate and timely diagnosis of the water production mechanism are required; improper diagnosis leads to ineffective treatment or inaccurate control; which consequently wasting of both time and money.

For the optimum treatment design, all data which consist of historical wells job, completion, production data, and reservoir data and the production data, must be available and revised thoroughly reviewed to ensure the wells were properly selected [7]. For the candidate selection criteria many different approaches are available, such as:-

- Shut-in wells or wells producing at or near their economic limit. (Minimize the risk in case of failure and reducing the treatment cost).
- Mobile oil in place, the wells at the water-out area as example is a bad candidate.
- High water-oil ratio.
- High initial productivity.
- Active Natural water drive wells.
- Structural position.

Water shut off techniques were used worldwide to avoid the massive water production; historically many material were used in the oilfields; [8] Studied the effect of the foam agent solution experimentally to show the feasibility of using the nitrogen foam in controlling the edge water. Also they used a numerical simulation to demonstrate the injection of foam into a horizontal well and 3 vertical wells. The result showed a significant improves in controlling the water cut in the horizontal section but the vertical wells are not effective.

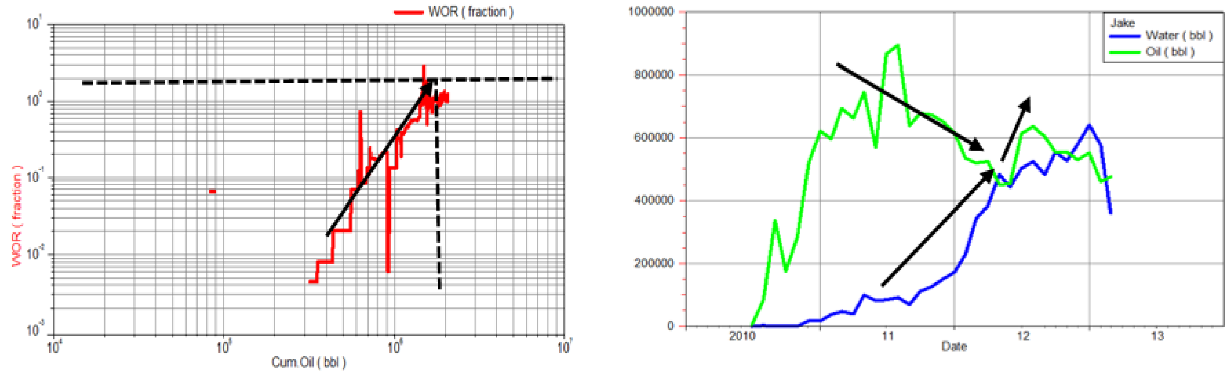
Although some operators performed water shutoff without clear diagnostic procedures, unsuccessful result have been obtained in the industry as stated by [2, 9] Communication degree between injection well and production wells was present in term of water control strategies by [10]currently, the important of diagnosis before any effort in treatment was stated by many authors [11,12].

Historically many diagnosing techniques were used to predict water production problem in the wells; well logging techniques (temperature logs, resistivity log, flow meter…etc.) were early used as an effective water production problem investigation technique; however the log interpretations and analysis are very complex, costly and limited to the direction of the wellbore [13,14]).

Due to the high cost of the production logging, another technique used for the diagnosis of water production problem is the Decline curve analysis (rate vs. time plot) or production rates vs. cumulative oil plot which is straight line plot; any fortuitous alteration in the slop is due to massive water production. The conventional water-oil ratio (WOR) vs. cumulative oil production in semi-log scale (Recovery plot) was early used in oil industry to analyze the production data[15]. See Figure 2.

A new technology was appear in 1995, when Chan proposed log-log plot of WOR and derivative of WOR versus time to differentiate between two coning and channeling using a three dimensional, three-phase black oil model. Chan reported three different periods in his plots. The first period known as departure time and starts from the begging of production to the breakthrough time, this stage is longer for channeling than conning. At the time of break–through, the WOR increases with time with different trends for coning and channeling. In coning, the WOR increases slowly and gradually approaches a constant value at the end of the second period. While in channeling the WOR increases relatively fast and slow down till it reaches a constant value. Finally, in the third period, the value of WOR increases very fast for both mechanisms.

Different conditions were studied by [16] for the WOR versus time using analytical studies and Chan’s plots; the work demonstrated that Chan’s plots has the ability to be a valuable water production problems diagnostic tool. Chan’s diagnostic plots were also demonstrated availability for horizontal wells as presented by[17].



Recover Plot

Production History

Figure 2: production history and recover plot

Chan’s plots and actual production history data have been used in Middle East sandstone oil reservoirs to generate log-log plots of WOR (water oil ratio) and the simple time derivative of water oil ratio (dWOR/dt) vs. time [18]. The work presented that Chan’s plot were found to be affective in differentiating whether the well is experiencing water coning (negative slope) or multilayer channeling (positive slope for the time derivative of water oil ratio curve). The diagnostic plots applied in this study provide a handy method for quick evaluation of excessive water production mechanisms in order to select wells candidates for water control treatment.

This paper discusses diagnostics and management evaluation for water production in Jake oil fields. There is no actual plan for water management in the field, only conventional shut-off methods have been tested with no success. The main purpose of the work is to illustrate the excessive water production mechanism to recommend the optimum shut off method and provide an effective treatment for the problems. No well logging data are available in the field under study; therefore, the production data were analyzed based on Chan’s Diagnostic plots as it is quick and reliable way and the lowest cost of all diagnostic methods.

2. Field Overview

Jake oilfield is located in the northeastern part of Muglad basin which is the largest known rift basin in Sudan interior, trending northwest-southeast and covering 120, 000 km2 Figure 3. The basin is around 800 km in length and 200 km in width. From the structural point of view, the Jake field can be divided into three compartments; the southern, central and northern compartments. The main formations is Bentiu with a 114.46 MMBbl reserve (The oil gravity range from 24.63 to 32.6API) and AbuGabra with 41.32 MMBbl reserve (The oil gravity range from 35.66 to 38.76API). Today the field production rate is about 20,000 STB/D to the Field production Facility (FPF) with 60 % water cut; due to the high water cut, only 11 wells are active wells while another 11 are shut down (five of them are closed due to high water cut) and three wells converted to water injectors.

The production history of the field shows a huge improvement after applying the gas Huff &Puff techniques at

2011 [19]; Gas lift is implemented after the huge drop of AbuGabra gas pool pressure in order to keep the production sustainable; Nitrogen injection was also used as a source of a high pressure to unload the wells. Water production increased rapidly throw the life of the field with a cumulative of 14 MMBbl by the end of 2014; the cumulative water bubble map Figure 4 presents that at least seven wells produced over 170,000 MBbl of water; and no actual plan for water management in the field, only conventional shut-off methods tests with no success are available; on the early stages of the field, only cement plugs or squeezes operations are the treatment methods for high water production problems.

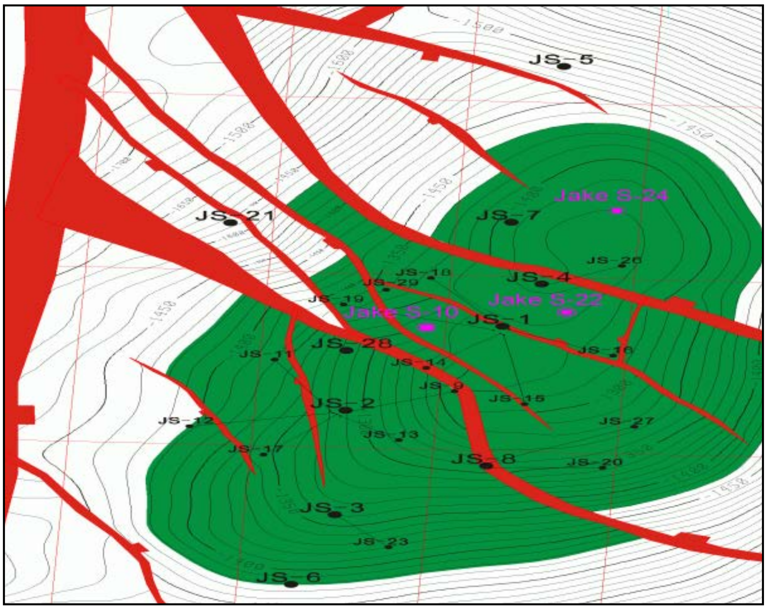


Figure 3: AG layer structural map Jake Field

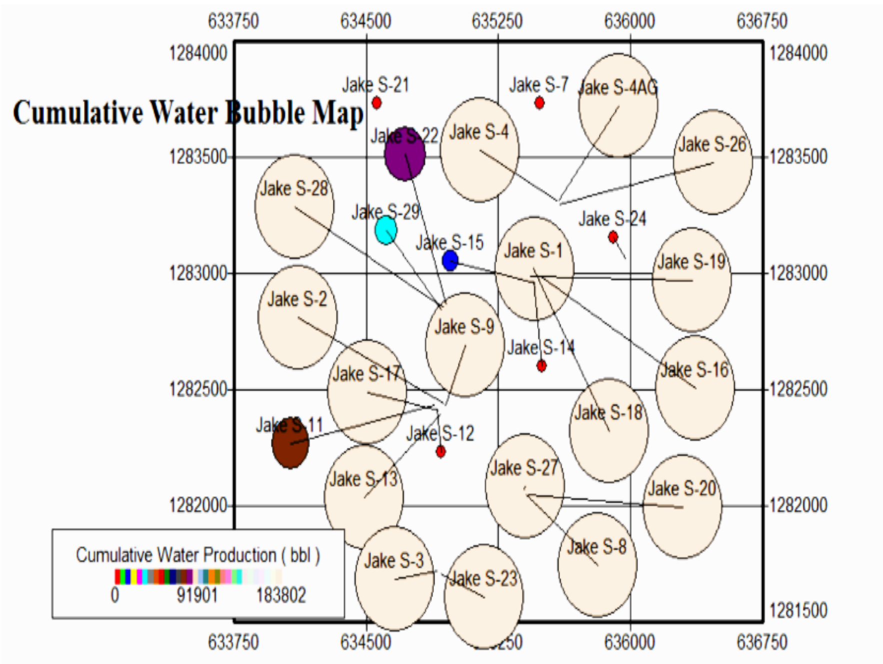


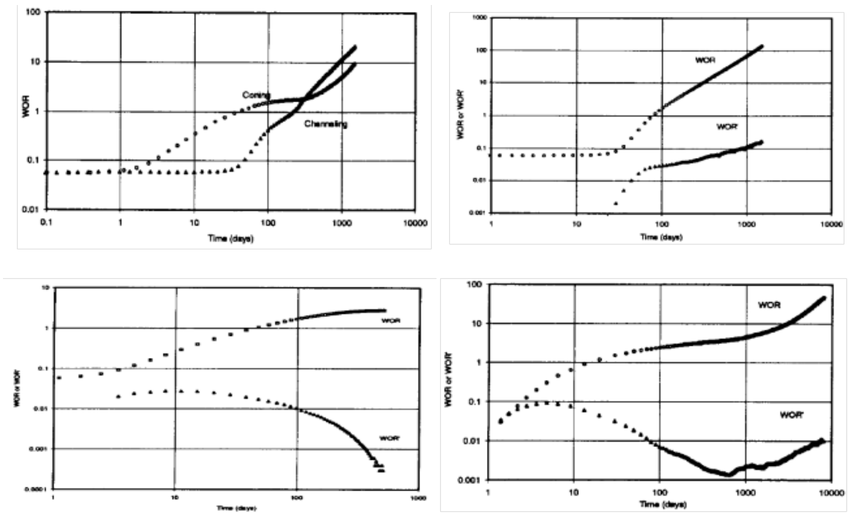
Figure 4: Cumulative water bubble map for Jake field (MBbl).

3. Data Analysis and Diagnostic Procedures

Analysis of the field production performance along with Chan's plots has been used for the field wells to identify the possible reasons of the unwanted water. Quit often it's not enough but it will give a guide lines for the wells to apply the suitable water shut-off technique or any other decision.

Chan's methodology is consist of plotting the water oil ratio WOR vs. time on a log-log shows a various trends for different mechanisms, the time derivative of the WOR dWOR/dt vs. time found to be capable of differentiating between conning, channeling or near wellbore breakthrough on the well level Figure 5.

The time derivative could be expressed mathematically as:-



$$WOR' = \frac{dWOR}{dt} = \frac{WOR_2 - WOR_1}{t_2 - t_1}$$

Figure 5: water control Diagnostic plots After [1]

4. Control of Excessive water production

The control options vary from simple to complex depending the type of the problem occurred at the well, more often when the problems are multiples a combination of solutions my required to do the effective job. The important factor is the cost; it will rise along with the complexity of the problem. The optimum selection for the candidate will help to decide the suitable method, the shutoff solutions is depend on the problem complexity, mechanical or chemical and the combination solutions are common if there is a multiple problems.

Mechanical options (packers or plugs) are the preferred choice in near wellbore problems, casing leaks, and flow behind casing. Also it can heal water-out layers without cross flow problems and the up-rising oil water contact. RPMs (relative permeability modifiers) could be used for sealing-off the water source with a chemical treatment such as polymer gel or in case of high permeability layer with bad water, there are many types of RPMs with a different chemical composition, distinguishing between them is depends on the type of the problem and the candidate for the water shut off treatment.

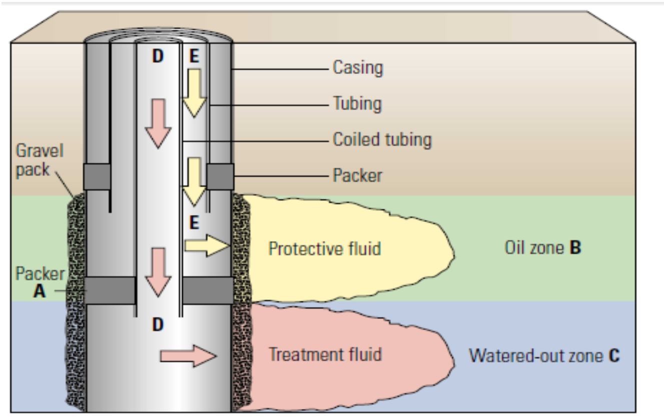


Figure 6: water shut off with treatment fluid. After [2]

Careful design and placement for the RPM treatment is crucial in order to get benefits from the treatment and not affecting the well performance such as increasing the drawdown pressure and decreasing the oil production.[2]

As general, water shutoff treatment fails to achieve desired results due to the wrong selection of the candidate well, the exact source of the water problem is not known and the suitable treatment method not selected. Furthermore the candidate well should be selected depend on the potentiality, structural position, significant mobile oil I place and a little risk if the treatments fails.

5. Discussion of Results

Nitrogen Injection and gas injection at some wells work very well to decrease the overall water cut of the field from 60 % to almost 30 % Figure 7, but the operational conditions is defining the effect of the injection process. Any instability or even a simple power trip could lead to major problems regarding the field oil production and the water cut behavior. And for the lead wells JS-1 decreased from 45% to 30%, JS-4 from60% to 35% but after a while the water cut increased again.

For the field wells, a well card to summarize the wells status According to Chan's plot results, the dominated water production mechanism is the high permeability layer channeling and that is justified because of the wells strata, edge water drive and the permeability variation. (Appendixes).

For example, the well JS-23 was completed as PCP producer on Nov.2010. The water cut started to increase quickly Figure 8 and shutting the lowers zones with bridge plug conducted on Nov.2010 with no significant change in the well performance, Chan diagnostic plots shows a normal trend indicating the area around the well is watered out. Further, the well converted on Mar.2011 to gas lift producer but because the well is near to the WOC it's transferred to water injector. Normal trend is Shawn in JS-20, the plots didn't shows clearly flat but this well is in the lower position of the reservoir and the water cut increase quickly. Figure 9 shows the well location, the possible suggestion is to transfer is to water injector just like JS-23 scenario to maintain the pressure and decrease the disposal water to the surface.

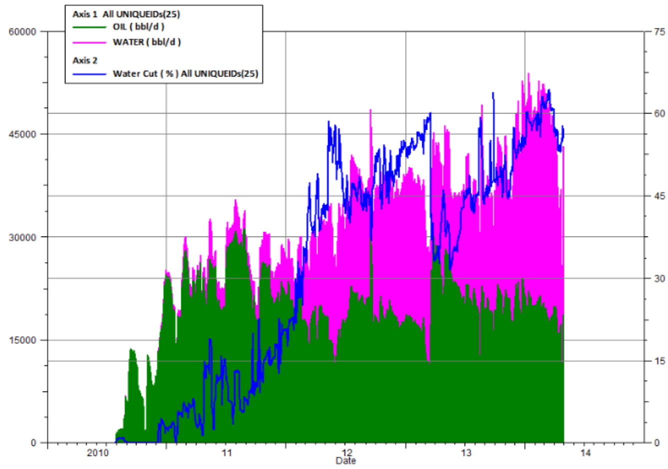


Figure 7: Jake filed production profile

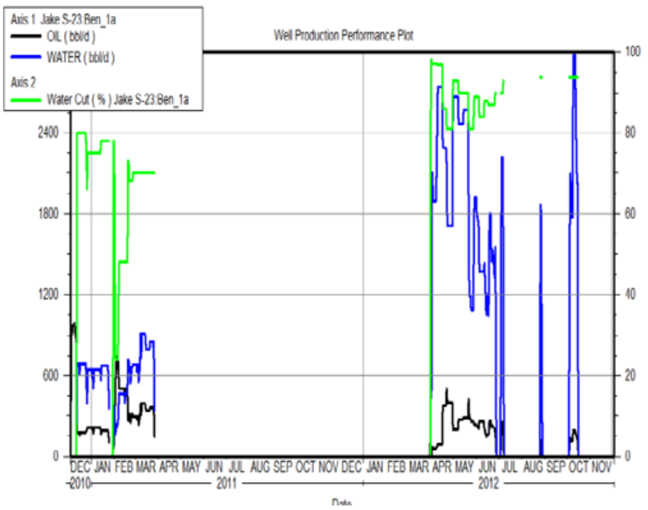


Figure 8: JS-23 production profile

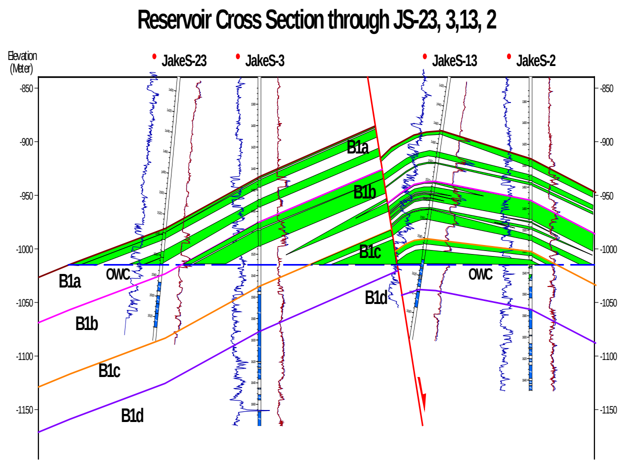
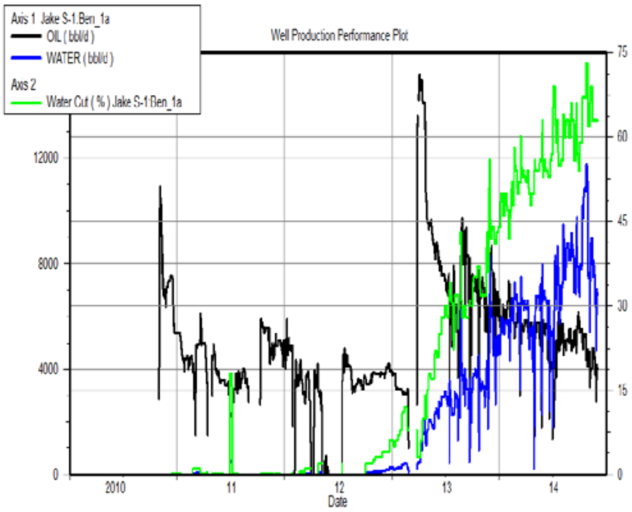


Figure 9: JS-23 structural position

The comingled well such as JS-2 Figure 12 which is producing from AbuGabra and Bentiu formations there is a clear bottom water conning but its need to confirmed first and the dominated mechanism to be verified with other methodology. According to [20] multi layers channeling will show a negative trend, which is an indication of conning mechanism according to Chan's methodology and he concluded that the plots are not totally general and could be easily misinterpreted. A separate zonal production [21] is proposed to identify the problematic layer sand shut them.



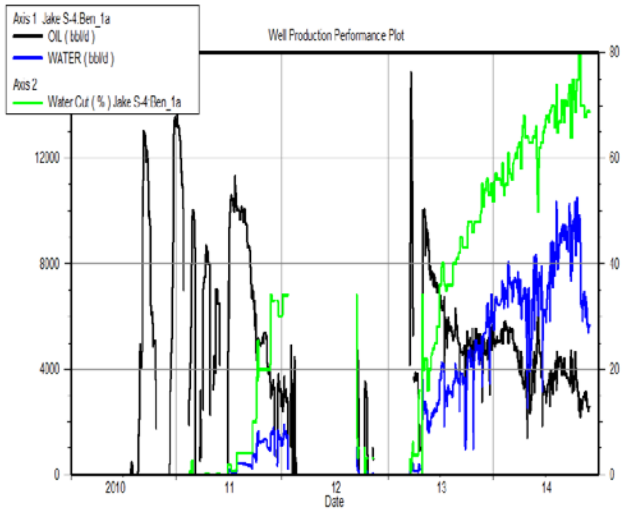


Figure10: JS-1 production profile

Figure 11: JS-4 production profile

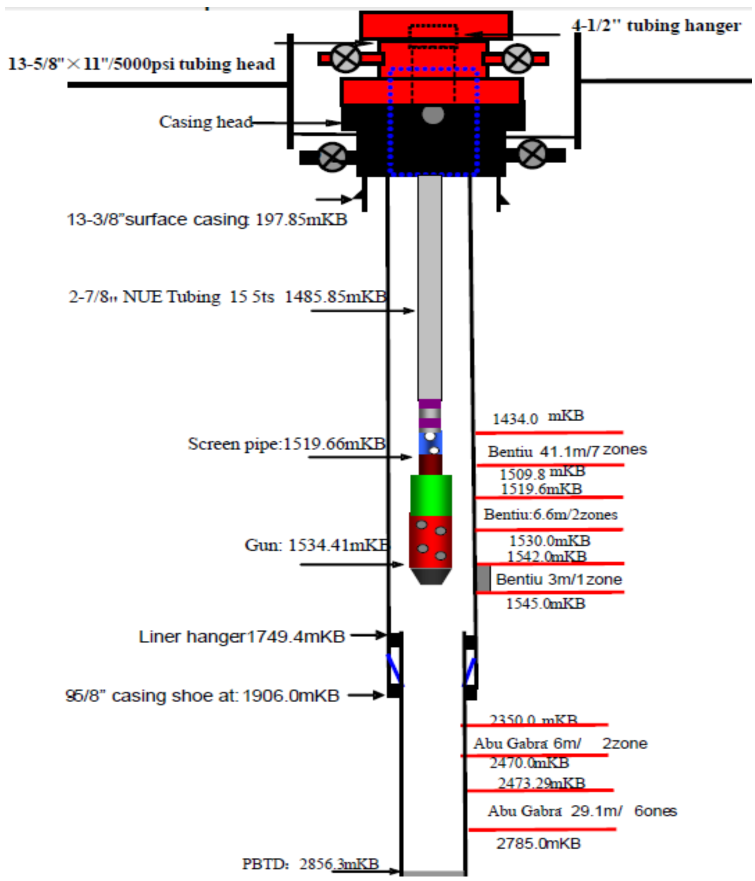


Figure 12: comingled well such as JS-2.

For JS-1 and JS-4 which they are the dominated producers Figure 10 Figure 11, the channeling behavior is so clear but its need to verified with the PLT the lower layers may affected by conning, both of them are completed as self-injection in the past with a high production rate and that caused a high drawdown to the reservoir and a fast increase in the water cut. Although there are producing the largest amount of the water both of them cannot be selected for a water shut off at this time.

Table 1 summarize the results and the wells are classified depend on the selection criteria with a risk factor from 1 to 10 to describe the ability to perform water shut-off:

Table 1: Results summary and wells classification

Classification	Well name	Diagnose	Well status	Structural position	High WOR	Risk Factor (1-10)	Next step suggestion
Group 1	JS-23	**Normal Trend**	Injector	-	No	-	-
	JS-20		Idle	No	No	-	Transfer to Injector
	JS-19		Idle	No	No	-	Transfer to Injector
Group 2	JS-8	**Channeling**	Idle	-	Yes	4	Further Analysis
	JS-9		producing	-	Yes	8	-
	JS-13		producing	Yes	Yes	8	-
	JS-16		Idle	-	No	4	Further Analysis
	JS-19		Idle	No	Yes	-	Transfer to Injector
	JS-26		producing	-	Yes	-	Optimization
	JS-27		producing	-	No	-	Optimization
Group 3	JS-1	**Multi layers Channeling**	producing	Yes	Yes	9	-
	JS-4		producing	Yes	Yes	9	Isolate lower zones
Group 4	JS-3	**Early Channeling with normal trend**	producing	Yes	Yes	5	Further Analysis
	JS-2	**Possible Conning**	Idle	Yes	Yes	2	Water Shut-off
	JS-18		Idle	Yes	Yes	3	Water Shut-off

6. Conclusions and recommendations

- All the wells under study are diagnostic a High Conductive layer channeling due to the edge water driver reservoir and the high vertical and horizontal permeability. Normal trends are in the watered out are wells.
- The comingled producer JS-2 and JS-18 showing a conning criteria due to the bottom water drive.
- Gas lift optimization (Injection rate, production rate) is a crucial to the water management strategy.
- The wells (JS-1, JS-4) which are the most dominated producers also suffering from a high channeling growing with time but due to the high risk factor any decision will be critical to the field production.
- Mechanical shut-off it's not a good choice for this kind of formations, JS-23 is failed. The RPM materials can give a good result but its need more investigation to identify the suitable material.
- There is no plan for the water management for the long term at the field so the gas injection should be continued in order to sustain the field performance and decrease or stabilize the water cut.
- The wells could be classified into 3 groups depend on their risk factor:-

  - ➢ High risk wells, JS (1, 4, 9, and 13).
  - ➢ Medium risk, JS (16, 3).
  - ➢ Low risk which there are the perfect candidates for performing water shut-off JS (2, 18).

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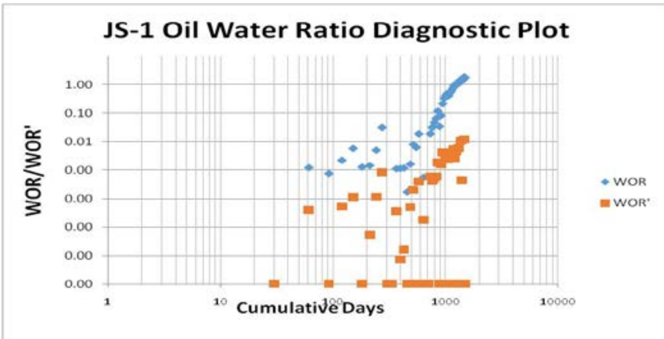
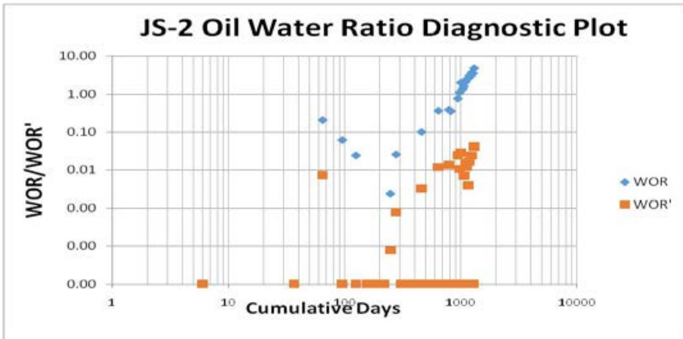
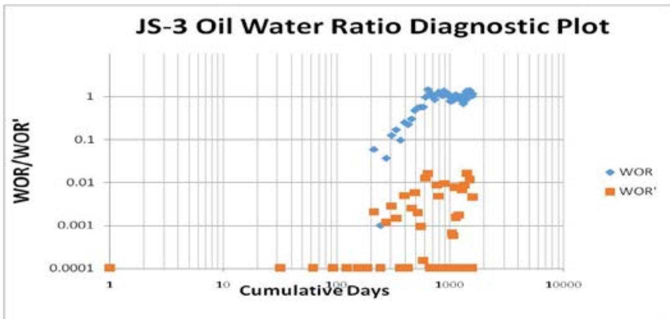
Appendixes



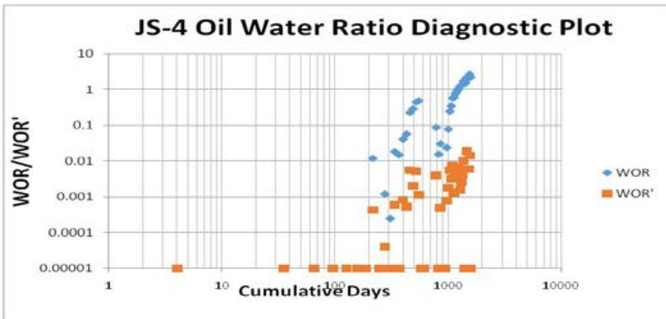
Multi layers Channeling



Bottom water conning



Early channeling and late normal behavior



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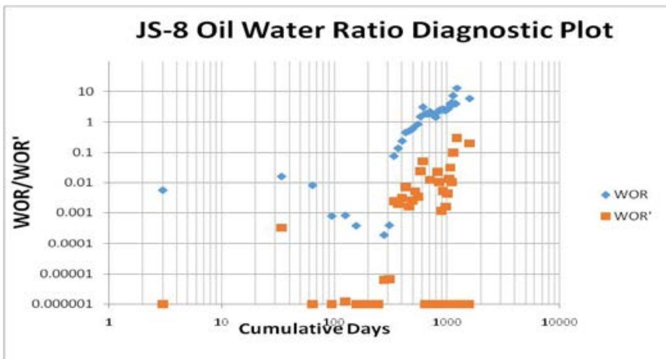
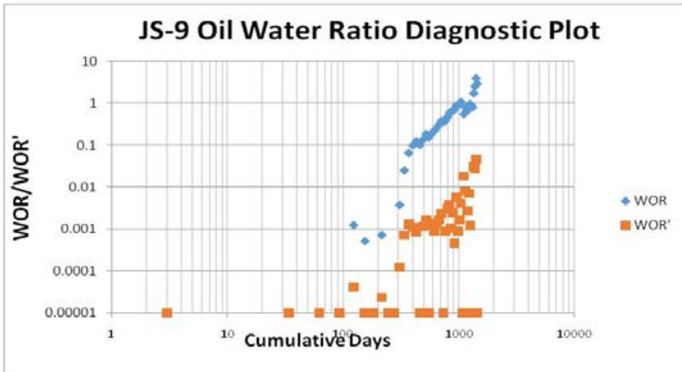


Channeling



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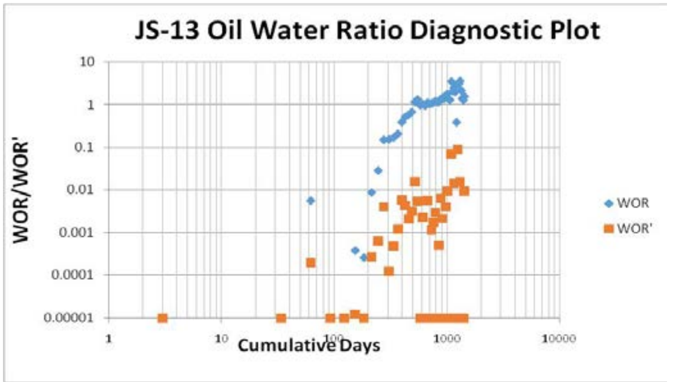
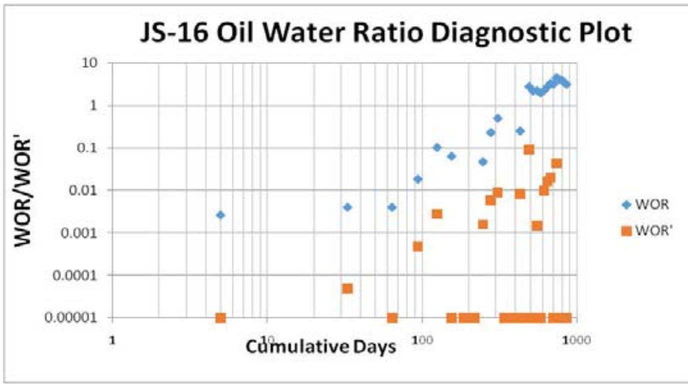
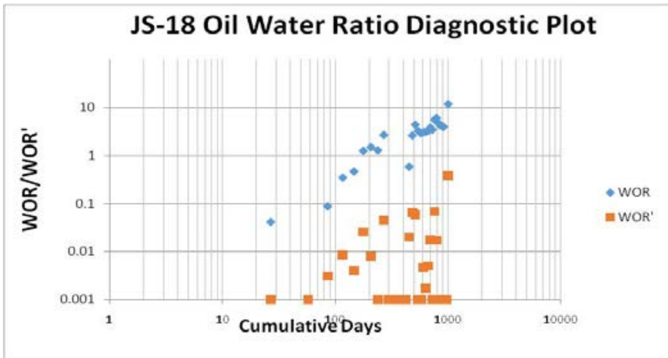


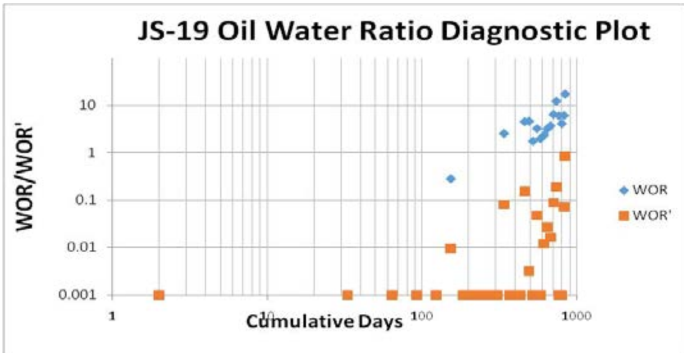
Channeling controlled by the nitrogen injection



channeling



Bottom water conning



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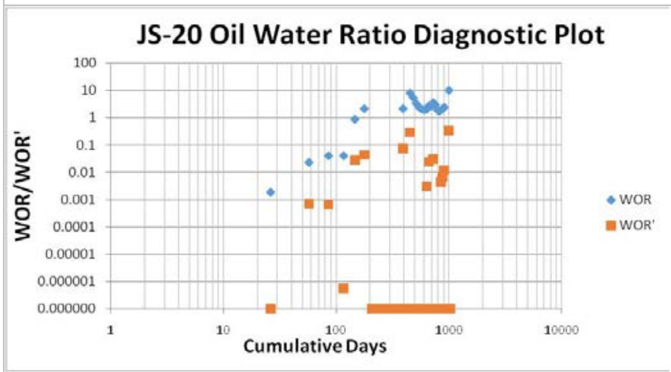
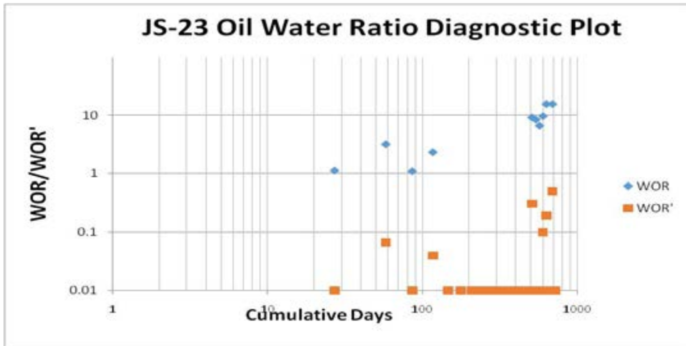


Normal, Area watered out



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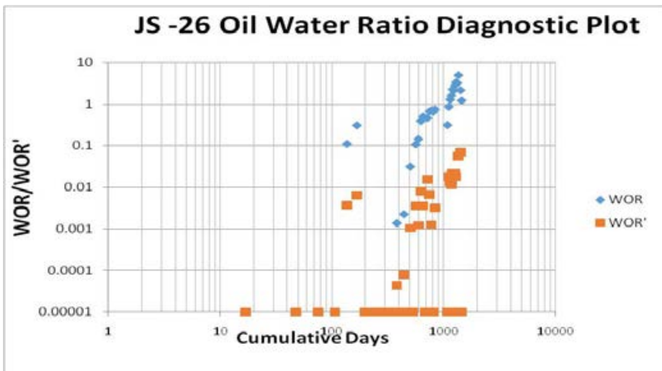

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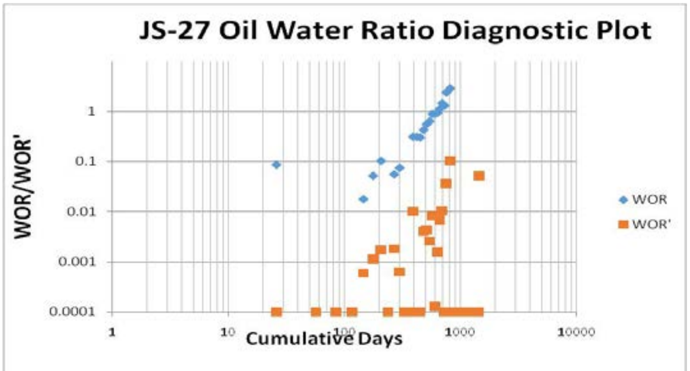

Channeling